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Mars Comm/Nav MicroSat Network

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Abstract. A recent Mars Exploration Program Architecture Definition Study, conducted by NASA with strong international participation, recommends establishment of a low cost *in-situ* communications and navigation relay satellite network to provide enabling and enhancing support for the international exploration of Mars. This would be the first step toward establishing a "virtual presence throughout the solar system" as called for in NASA's Strategic Plan. The Mars satellite network concept, and its evolution from a prototype launched in 2003 to a full constellation, is described. Implementation of the Mars satellite network will utilize the common micromission bus being designed for piggyback launch by Ariane 5 as described in a companion paper, "The Mars Micromissions Program." The requirements imposed on the common micromission bus to meet the needs of the Mars MicroSat network are discussed. A functional description is provided for the MicroSat payload, a UHF transceiver system, which supports the *in-situ* communications and navigation needs of user missions. Key technologies that are expected to play an important role in the implementation of the MicroSat network are also discussed.

Introduction

Beginning in the summer of 1998, NASA undertook a reassessment of the overall program of Mars exploration and set an updated course for the future. JPL was tasked to lead this Definition Study for the future Mars Exploration Program Architecture. Sensing that this program would require broad involvement of many stakeholders, JPL sought participation by other NASA centers, including those involved in the Human Exploration and Development of Space Enterprise (HEDS), as well as strong participation by international partners, including the space agencies of Europe, France and Italy. A number of technical working groups were formed, to conceptualize the various program elements and begin the detailed engineering that would turn these into reality. One such working group was chartered to investigate a so-called "Mars Infrastructure." This element would have the purpose of significantly improving the ability to communicate with, and provide navigation for, assets at Mars. Essentially, it would begin the establishment of a "virtual presence throughout the solar system" as called for in NASA's Strategic Plan. Recommendations of this working group include establishment of a low cost *in-situ* communications and navigation relay satellite network to provide enabling and enhancing support for the international exploration of Mars.[1] Response to the proposed comm/nav satellite network has been very favorable, resulting in funding of a phase A study being conducted this year.

Extensive analyses and numerous studies over the last few years have consistently demonstrated the benefits of low-altitude Mars relay satellites for support of landed elements.[2, 3, 4, 5] Implementation of the Mars satellite network will utilize the common micromission spacecraft bus being designed for piggyback launch by the Ariane 5 as described in a companion paper, "The Mars Micromissions Program."[6] The focus of this paper is on the application of the micromission bus to the comm/nav MicroSat network and the MicroSat payload, a UHF transceiver system for supporting *in-situ* relay communications and navigation needs of user missions. The MicroSat network concept and the evolution of its functional capabilities from a prototype launched in 2003 to a full constellation are described. Important comm/nav MicroSat functional requirements on the common micromission spacecraft bus are presented with discussion of the mission-system tradeoffs for the driving requirements. The functional design of the UHF comm/nav transceiver system is also described. Finally, the paper includes discussion of those technologies which are of specific importance to the implementation of the comm/nav MicroSat network.

Mars Network Concept

The Mars communications / navigation network, as it is envisioned when fully evolved, is depicted in Figure 1. When complete, the network is planned to include both a constellation of relatively low-altitude, low-cost MicroSats and a small number of larger Mars areostationary satellites (MARSats). Implementation of the network is planned to begin with the gradual emplacement of the low-cost MicroSats for support of the near-term robotic exploration and sample return missions. The larger, more capable MARSats will be deployed when required for higher capacity support of robotic outposts and eventual human missions. The strategy for the evolving Mars network is shown in the timeline of Figure 2. This paper is limited to discussion of the MicroSat elements of the network.

The first MicroSat, which is considered a prototype, is planned to be launched for injection to Mars in the 2003 opportunity, and eventual positioning in an 800-km altitude, near-equatorial orbit. Two more MicroSats will be launched to Mars on each succeeding Earth-to-Mars opportunity (~ 26 months), targeted for near-equatorial and high inclination orbits as needed. Equatorial MicroSats provide excellent connectivity to low-latitude landed-elements, which are expected to include most sample return operations. The near-polar MicroSats round out the constellation by providing global coverage for the benefit of higher-latitude surface elements. Six MicroSats are nominally planned for the steady-state constellation. More would be desirable, especially for real-time positioning, but budget constraints will likely preclude this.

The MicroSat is first launched into a geosynchronous transfer orbit (GTO) as a secondary payload on the Ariane 5 launch vehicle. After transitioning into an Earth-Moon phasing orbit, the MicroSat injects to Mars on the date dictated by the Moon-to-Earth geometry. The technique enabling this low-cost approach was first proposed by Blamont[7] and subsequently extended by others.[8, 9, 10] Upon arrival at Mars, the MicroSat propulsively inserts into a highly-elliptic capture orbit and aerobrakes into a final low-altitude circular orbit. Even with the use of aerobraking, it is necessary to expend nearly two thirds of the 220 kg launch mass to provide all the ΔV required to arrive at the operational Mars orbit. The actual

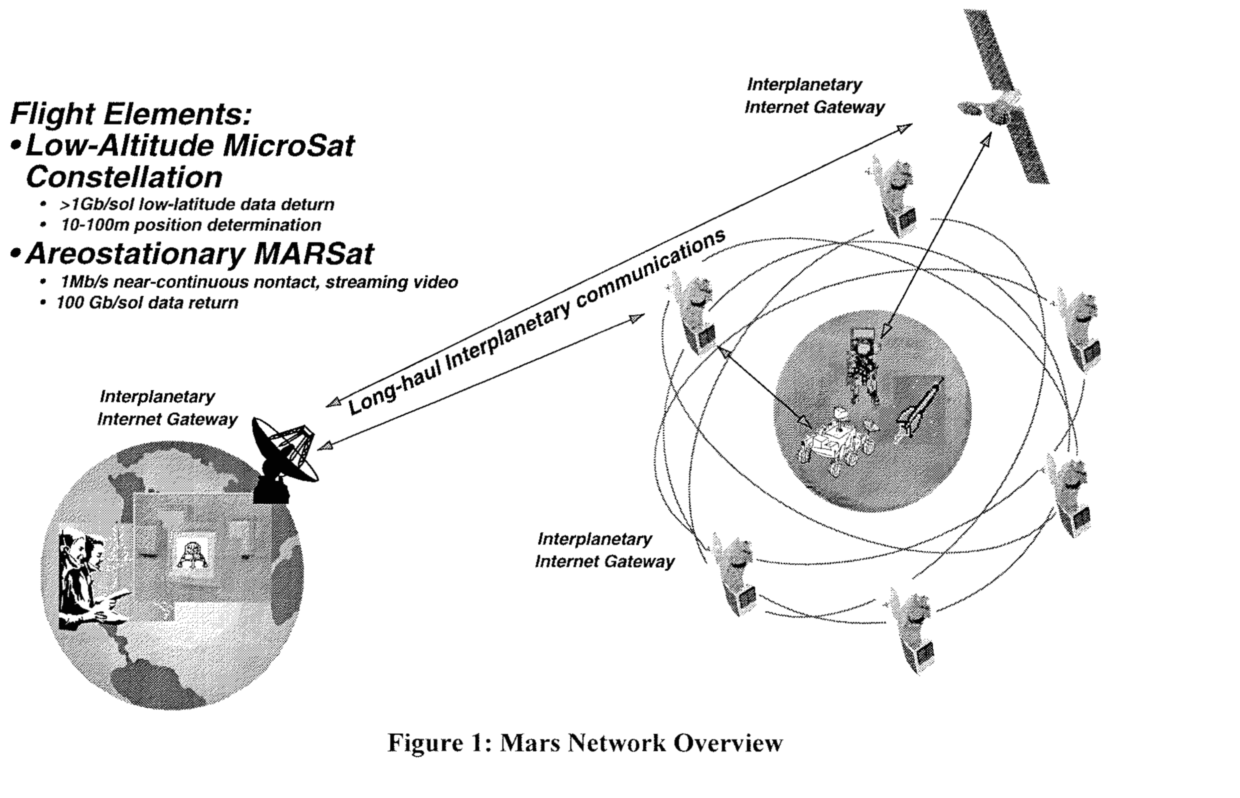

Figure 1: Mars Network Overview

communications and navigation payload is limited to 6 kg[6] for the 2003 opportunity. Despite the modest size of the payload, the MicroSats will provide noticeable improvements in connectivity and end-to-end data volume as illustrated in Figure 3, and, when fully evolved, will enable position determination in a manner analogous to that of the GPS satellite system at Earth. Recent efforts[11, 12] have considered an array of candidate MicroSat constellation configurations and analyzed the ability of each to satisfy user requirements. Additionally, evolution of the communications and navigation performance of these constellations, as they are emplaced and replenished, has also been examined.

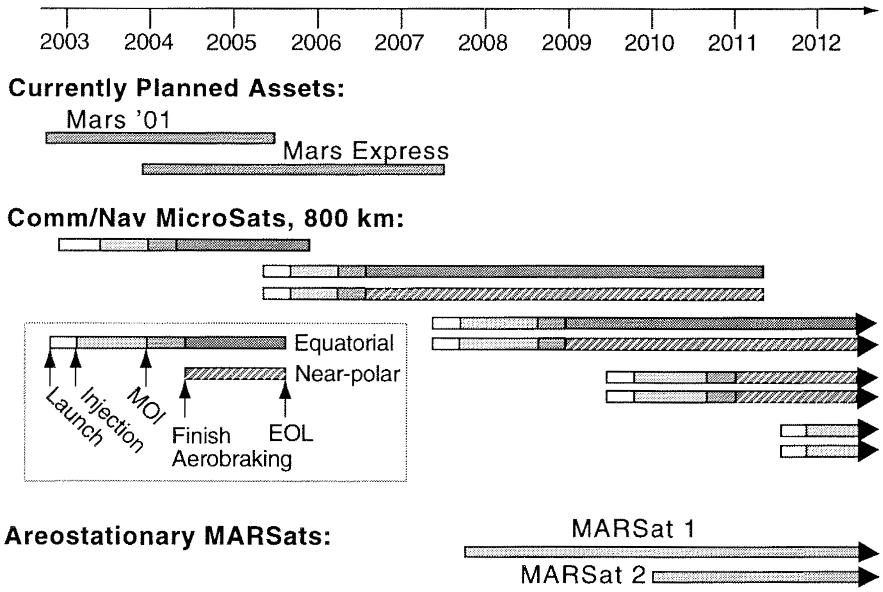

Figure 2: Strategy for an Evolving Infrastructure

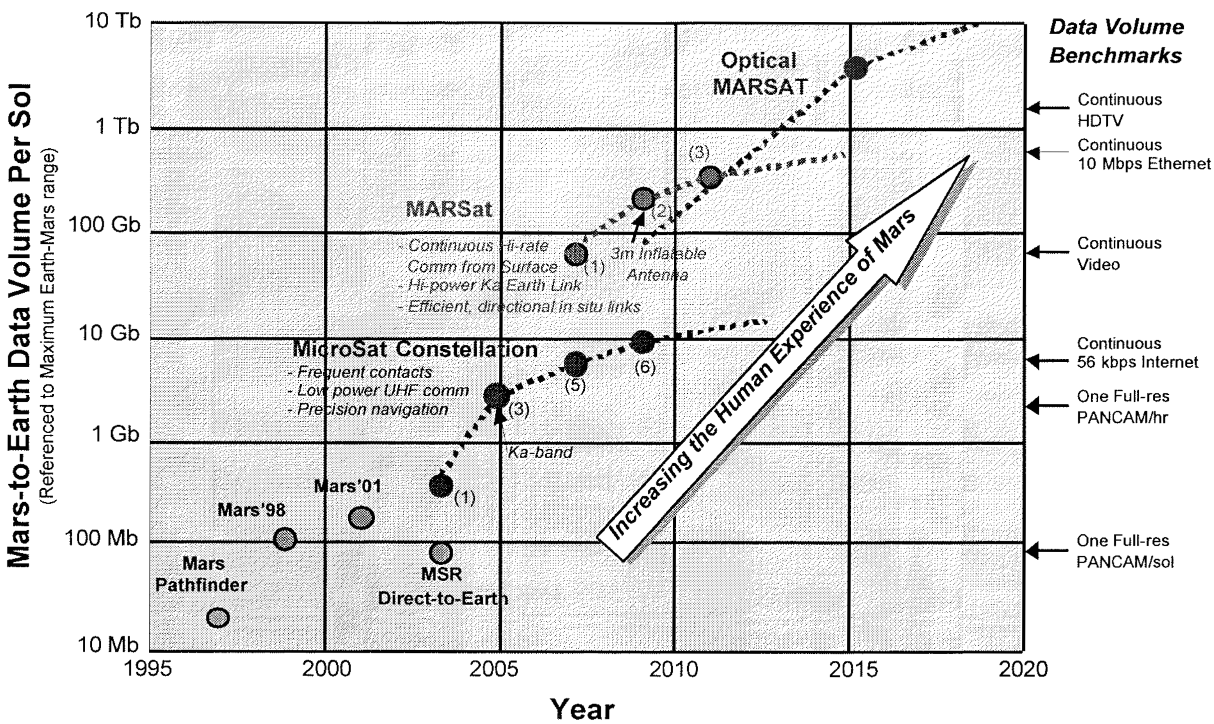

Figure 3: Mars Network Evolving Capability

The Mars network will be linked to the large deep space tracking antennas located on Earth, which are primarily comprised of the antennas of NASA's Deep Space Network, located in the California desert, Spain and Australia. However, tracking assets of other nations are expected to interoperate with the DSN so as to expand capacity and support the overall effort. Indeed, the Mars network can be thought of as an extension of DSN nodes and services to the Mars in-situ region. The concept has been likened to the beginnings of an interplanetary Internet that will bring the exploration of Mars right into the homes and schools of the public so they can participate in the martian adventure.

Comm/Nav MicroSat Requirements

Utilization of the common micromission spacecraft bus to meet the requirements of the comm/nav MicroSat presents a formidable challenge because of the severe mass and volume constraints associated with launching piggyback on the Ariane 5. Feasibilty of the piggyback launched comm/nav MicroSat has been demonstrated by a JPL design as well as several designs developed early this year by industry in competitively awarded Mars MicroSpacraft Bus Feasibility and Design Concept contracts. Figure 4 illustrates a representative comm/nav MicroSat configuration based on the JPL common micromission bus design.

The driving requirements imposed on the multi-mission spacecraft bus to meet the comm/nav MicroSat needs involve total ΔV, aerobraking, Mars-Earth communications, UHF payload accommodation and lifetime.

There is a price to pay for the piggyback launch to GTO on the Ariane 5. Up to about 1600 m/sec ΔV are required by the micromission spacecraft to complete the transition to an Earth-Mars transfer trajectory. In addition, compared to the use of the micromission bus simply as a carrier for delivery of Mars probes, the comm/nav MicroSat requires substantially greater ΔV to be captured into Mars orbit and achieve the final 800-km circular orbit after aerobraking. The total specified ΔV for the 2003 MicroSat is 2700 m/s compared to 1650 m/s for the 2003 probe carrier aircraft mission. The extra propellant mass associated with the large ΔV demands that advanced light weight components and structural design are used throughout the micromission bus in order to provide an acceptable mass margin. The propulsion requirements are even greater for MicroSats launched in the 2005 opportunity, so it will be necessary to phase in additional mass saving technologies after the prototype 2003 mission.

Aerobraking, from the initial capture orbit down to a low altitude orbit, is required to avoid an even greater ΔV requirement. Aerobraking is a proven technology, which will have been used at Mars by several spacecraft prior to the 2003 MicroSat (1996 Mars Global Surveyor, 1998 Mars Polar Orbiter and 2001 Mars Surveyor Orbiter). Although there will have been aerobraking design and operations experience, aerobraking will require special attention for the MicroSat because analysis has indicated that the "banana" shaped configuration (required for piggyback launch on the Ariane) would be unstable in the drag environment unless the relationship between the center of pressure and center of gravity are carefully controlled (e.g., by means of deployed solar panels or drag flaps).

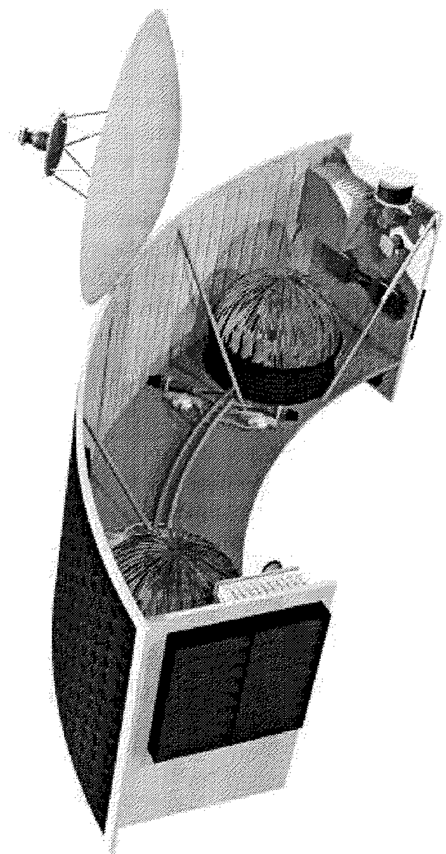

Figure 4: Representative MicroSat Design Configuration

To assure adequate capability to return user data to Earth, the minimum data return volume via the MicroSat to Earth communications link is specified as 200 Mb/sol at maximum range (2.7 AU). This is based on 10 hr maximum transmission time per sol to the DSN via a 34-m BWG antenna assuming X band. This requirement far exceeds the data rate required for the probe carrier, and can only be met by the use of a high gain antenna, which would not be required for the probe carrier.

The UHF payload is limited to 6 kg for the 2003 prototype MicroSat. Multiple UHF antennas may be utilized, and a medium gain antenna (~ 10 dB) is being considered. Mounting of the UHF antennas will require careful design coordination with deployable booms being considered to achieve satisfactory antenna patterns.

Lifetime of the MicroSats is, of course, a very important parameter for the establishment and maintenance of the Mars network. However, the mass constraint will not permit the use of extensive redundancy as is the usual practice for long life communications satellites at Earth. As the common micromission bus must be largely single string, long life must rely on a good simple design, judicious component selection, well planned and comprehensive testing, and carefully controlled operations. For the prototype 2003 MicroSat, the required lifetime is specified as 3 years from launch with a goal of 5 years. For network planning, the lifetime of future MicroSats is assumed to be 5 years in Mars orbit. This improvement is expected to be possible from the experience gained in the implementation of the prototype 2003 MicroSat. The low cost of the MicroSats makes it possible to achieve overall network robustness by the launching of multiple MicroSats.

MicroSat UHF Transceiver System Functional Design

The MicroSat Ultra High Frequency (UHF) transceiver payload will provide data communications relay and navigational services to user platforms in the vicinity of Mars. Each transceiver will operate as a node in an autonomous network of assets, establishing and maintaining a spatial and temporal Mars reference frame to which user platforms, either landed, roving, flying, orbiting, or on an incoming trajectory will be tied. The transceiver being developed for the launch opportunity in 2003 is the first in a series of increasingly capable transceivers to span the first decade of the next millennium. The transceiver is designed to minimize dependence on Earth-based assets by carrying an Ultra-Stable Oscillator (USO) which allows autonomous Mars frame ties to Earth using time sparse one-way links.

There are three key features that distinguish this transceiver from typical radios used for in-situ communications.[13, 14] First, the transceiver has been designed from the start to support multiple simultaneous users. The current draft issue of the Proximity-1.0 Space Link Protocol from the Consultative Committee for Space Data Systems (CCSDS)[15] defines a Frequency Division Multiple Access (FDMA) scheme that is baselined for the 2003 version of the transceiver. Alternate multiple access methodologies will be explored as part of the ongoing transceiver evolution. Second, this transceiver integrates high precision, radio metric tracking and observable generation (e.g., phase and range) with a high-rate, highly programmable communication channel. Thus the transceiver will, while providing state-of-the-art communications performance, allow the Mars network to provide near real-time (evolving network) and real-time (fully evolved network) navigation services. Third, the transceiver incorporates a powerful microprocessor that executes high-level software. This software performs many tasks including Proximity-1.0 packet and session layer protocol functions (e.g., packetization, link negotiation, multiple user channel allocation), autonomous Mars/Earth frame ties using Earth-to-MicroSat one-way Doppler observables as well as providing the user navigation services mentioned above.

The transceiver can be functionally divided into three sections as shown in Figure 5: 1) a radio frequency (RF) subsystem, 2) a digital channelization subsystem, and 3) high-level processing subsystem.

These three subsystems are described in some detail below, addressing how they are being designed for the first MicroSat in 2003 as well as specifically where enhancements are being considered in order to improve performance as the Mars network evolves.

Subsystem Descriptions

The *RF subsystem* implements the analog functions found in the transceiver. A separate receive module for each one of three antennas down converts signals received in the UHF band between ~ 400 to ~ 405 MHz to a low intermediate frequency (IF) where they are digitized. It also up converts multiple, digitally generated transmit streams to the UHF band between ~ 435 to ~ 442 MHz and amplifies them before transmission either through one of two low gain, hemispherical coverage antennas or through a directional medium gain antenna. A key design feature of the down converters and up converters is their fixed local oscillator (LO) frequency, wide-band operation. This permits a simpler design and provides for easier accommodation when bandwidths and/or signal structures evolve over the build-up of the Mars network. The design calls for the pair of low gain antennas (nominally + 0 dBi) with boresights in opposite directions to permit full user coverage without requiring maneuvers. Use of the medium gain antenna (nominally + 10 dBi) with its narrower, fixed pattern may require spacecraft maneuvers to achieve user coverage. Higher gain as well as beam steered antennas will be studied for inclusion in future transceivers as ways of improving connectivity (higher gain) and reducing operational complexity (beam steering).

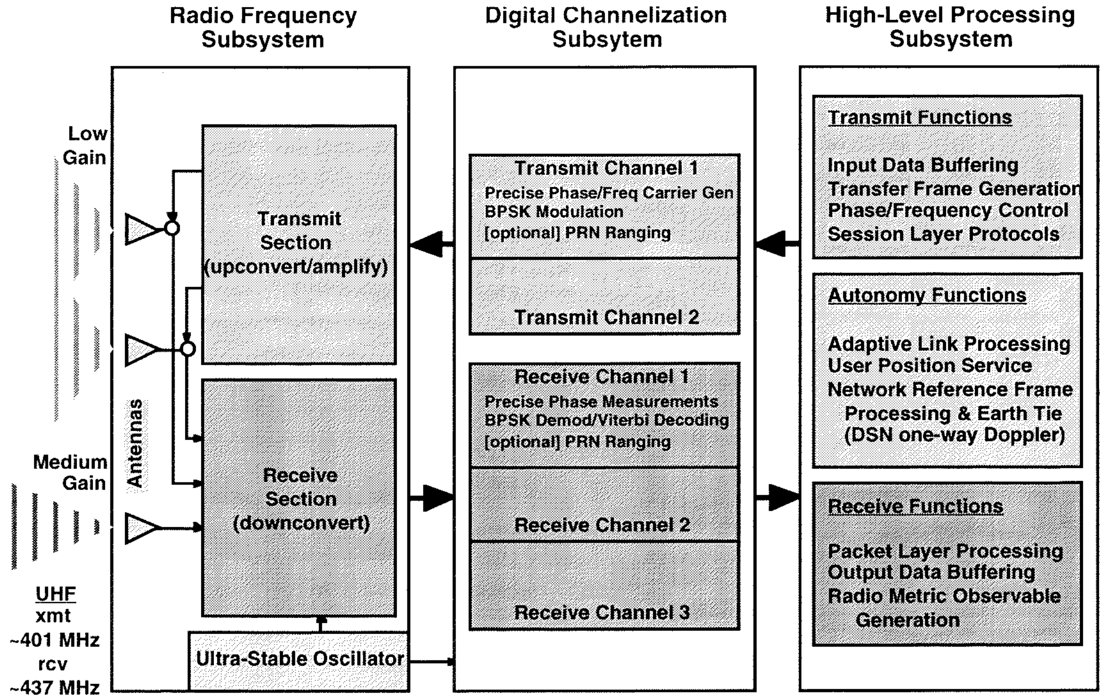

Figure 5: Functional Block Diagram of the MicroSat UHF Transceiver

The *digital channelization subsystem* consists of multiple transmit and receive channels. The receive channels process the user transmitted signals and, using digital channelization, precisely track the carrier, demodulate the binary phase shift keyed (BPSK) data, perform Viterbi decoding and [optionally] track a pseudo random noise (PRN) ranging signal. Each transmit channel generates an independent carrier, allowing precise control over phase and frequency (implements FDMA digitally). In addition, a dynamically variable rate, output data stream is encoded [convolution encoding is optional] and BPSK modulated on each carrier. A further option is to BPSK modulate a PRN ranging code onto the carrier, either in place of or in addition to the output data. If the latter option is chosen, a severe limitation is placed on the output data rate relative to the PRN ranging code rate in order to preserve link performance. Future transceivers may incorporate a new signal structure being researched at JPL that will permit higher rate data communications in the presence of a PRN ranging signal. The above functions will be implemented using high-speed programmable hardware (e.g., field programmable gate arrays (FPGA)) in combination with fast, optimized software routines running on either a digital signal processor (e.g., Motorola 56XXX family) or a general purpose microprocessor (e.g., IBM/Motorola PowerPC family).

The *high-level processing subsystem* will be implemented in a programming language and will execute on a general-purpose microprocessor. Many of the tasks expected to run on this processor have been mentioned above but the key items will be reviewed here. In the communications services category, the packet and session layer protocols from the Proximity-1.0 recommendations will be implemented in software. While the packet layer has been implemented in hardware, the session layer algorithms for link establishment, maintenance, and adaptive rate changes, all in a multi-user environment, will be easier to develop and qualify for flight in software. In the navigation services category, software will perform smoothing and fitting of raw radio metric observables, phase (integrated Doppler) and range. On-board navigation algorithms use the resulting time sequence of phase and range to determine the location of the user. As more MicroSats arrive at Mars, it will be desirable to establish cross-links ("cross" simply meant to distinguish these from user links) in order to acquire radiometric phase and range data between MicroSat payloads. Navigation algorithms executing autonomously on-board will use these observables, along with those from users at known locations (e.g., landers) or users with their locations determined by other means (e.g., orbiters with two-way DSN links), to maintain Mars network spatial and temporal reference frame. Finally, as mentioned previously, because the payload includes a USO, one-way phase / Doppler measurements made on the Earth-to-MicroSat link by another spacecraft transceiver can be used autonomously by similar navigation algorithms to tie the Mars temporal and spatial reference frames back to the Earth frame.

Overall, the hybrid implementation (software + programmable hardware) chosen here is intended to be very flexible and allow the transceiver to be more easily adapted to evolving network operations both before and after launch. Another desirable feature of this implementation is built-in support for user radios with a wide range of capabilities—from the simplest beacon to full-duplex, coded links with simultaneous two-way Doppler and range capable transceivers.

User Services

From the user's perspective, services fall into two categories: communications services and navigation services. The Mars network MicroSats will provide these services to a multitude of users simultaneously. The key to providing these services is the UHF Transceiver, whose characteristics are shown in Table 1.

The transceiver provides *communications relay services* to all users in the vicinity of Mars. Specifically, commands and data relayed from Earth to the transceiver will be routed to the specified addressee once a link can be established with that user platform. The transceiver supports a wide range of data rates (both coded and uncoded) on both the forward and return user links. In addition, during a contact period, the transceiver will be capable of initiating a negotiated data rate change in order to take advantage of changing link characteristics and maximize data return per unit time. Since the payload will (initially) rely on the spacecraft flight computer to provide data buffering, any telemetry received from the user during a contact period will be passed to the flight computer for buffering and subsequent relay to Earth. In order to support multiple simultaneous users, both the Proximity-1.0 link specifications and the transceiver itself incorporate special features.

The link specification incorporates a Frequency Division approach to both duplex communications (FDD) as well as multiple, simultaneous access using FDMA. As mentioned previously, the payload will be capable of receiving and transmitting multiple, frequency-offset signals within a single allocated frequency band, in this case UHF. The design choice of wideband analog processing coupled with digital channelization allows the transceiver to achieve this functionality. Future versions of the transceiver will take advantage of advances in microcircuit integration to further increase simultaneous channel capacity without increasing power or mass (perhaps even reducing both). Future link specifications may also incorporate Code Division Multiple Access (CDMA); a feature that can easily be supported by the UHF payload since it employs flexible PRN generators for ranging purposes.

Table 1: UHF Transceiver Characteristics

Frequencies	Forward: 4 @ 401 MHz band Return: 20 @ 435 MHz band
Multiple Access	FDMA (2003)
Data Rates	1, 2, 4, …, 512, 1024, 2048 kbps
Bit Error Rate	$< 10^{-6}$
Coding	Uncoded or Convolutional (k = 7, r = 1/2) Reed-Solomon / Turbo Codes (2005+)
Carrier	Suppressed or Residual (mod index = 60%)
Modulation	BPSK or Pure Tone
Simultaneous Users	2 (2003) 5 or more (2005+)
Protocols	CCSDS Proximity-1
Phase Precision	0.5 mm @ 1 sec
Range Precision	10 cm @ 10 sec
USO Stability	5 parts in 10^{-14}
Mass (not inc. antennas/cables)	< 2.0 kg
Power	< 7 W (receive only w/ 2 users) < 26 W (total w/ 10 W transmitter)

The transceiver *navigation services* start with precise phase tracking of a user's carrier signal (suppressed or residual) on the return link (without degrading performance). This observable, a sequence of time-tagged phase measurements (integrated Doppler), will be available for navigation processing for virtually all users. If the user is equipped with a coherent transponder or equivalent, then carrier phase can be processed as a stronger, two-way observable. Otherwise, observables are called one-way and, unless they are differenced with simultaneous phase observables from another MicroSat or user radio, they are subject to errors introduced by the user's on-board frequency standard. The payload will carry a USO in order minimize the effects of transceiver clock stability on phase observables. If the user is equipped with a compatible, range-capable radio, then the MicroSat and user can negotiate a short burst (order of seconds) of ranging at key times during a contact period. This will provide an observable (again, either one- or two-way depending on whether the user can transmit as well as receive a PRN or Tone ranging signal), which measures the absolute distance between the MicroSat and user. If the range is one-way, it will also include offsets and drift in the user frequency reference. These data types, one-way, differenced one-way, two-way phase and one-way or two-way range, are processed on-board to produce real-time or near real-time user position and time synchronization. These parameters can then be included in the packet stream on the user return link.

The preceding paragraphs describe a Mars network-centric approach to user navigation services. This takes advantage of the fact that the Mars network nodes will have knowledge of their location and time, referenced to a Mars coordinate frame, and will possess the spare computing power to process the above observables into user position and time calibrations. Alternatively, users who carry sufficiently capable computing subsystems and radios may be able to take advantage of a second type of navigation service planned for MicroSats. In 2005 and beyond, a Global Positioning System–like beacon is broadcast such that, when received by a user simultaneously from multiple, spatially distributed MicroSats, the user can compute their own position and clock offset within a Mars reference frame. This service would operate in much the same way as GPS does for Earth and near-Earth users.

Technology Applications

Significant technology advances may be expected to play an important role in the implementation of the MicroSat Network.

As has been noted, implementation of the MicroSat network is very challenging both from the standpoint of providing maximum communications / navigation capability for user support and designing within the Ariane 5 secondary payload launch constraints. Many advanced technologies, which appear promising for MicroSat application, are listed in Table 2.

Several of the technologies shown in Table 2 should be available in time for the 2003 prototype mission, while others have later projected application as the network evolves. It is believed that many of the technologies could be developed in time for the 2005 opportunity, which will be especially challenging because it ranks as a worst case opportunity in terms of ΔV requirements and mass margin.

Table 2: Applicable Advanced Technology

	Potential 1st Utilization (Mars Launch Opportunity)
• Propulsion	
– Lightweight components (valves, etc)	2003
– Miniature ACS thrusters (0.01–0.1 N)	2005
– Higher efficiency main thrusters (320–330 sec)	2005
• Deep space communications	
– Spacecraft transponding modem (STM) for Earth link	2003
– Ka-band and high efficiency power amplifier for Mars-Earth link	2005
– Inflatable reflectarray / solar array	2007
• *In-situ* Communications	
– Lightweight UHF transceiver	2005
• Ballute for aerocapture	2005

Propulsion

A few advanced propulsion technologies, which can benefit the MicoSat by saving mass and/or improving performance, are currently being supported to meet the schedule of the 2003 MicroSat. These include lightweight, dual-mode biprop valves and filters, ultra-thin lined, composite over-wrapped propellant tanks, and 1-N monopropellant attitude control thrusters with 1-mN-sec minimum impulse-bit capability. Light-weight 22-N main thrusters with higher efficiency (310–325 sec, vs current 295 sec) may also be available for the 2005 opportunity.

Deep Space Communications

New deep space communications technologies, which may be expected to play significant roles in the implementation of the MicroSat network include use of the next generation spacecraft transponder (Spacecraft Transponding Modem), use of the Ka frequency band between Earth and Mars, and use of printed reflectarray antennas. These technologies flow from the requirement for smaller, more efficient and inexpensive spacecraft.

The Spacecraft Transponding Modem (STM) is in development on a schedule to support the 2003 MicroSat. It uses new technologies to achieve lower mass (1.3 kg), smaller volume (525 cm^3), lower power requirements, lower parts count, and lower recurring costs, while providing many new and improved capabilities over previous generation transponders. The STM includes an X-band receiver, an X-band exciter, and a Ka-band exciter. The STM supports Reed-Solomon and turbo coding, which allows higher data rates to be realized for a given telecom system.

Ka band can be used to increase the performance of the Mars-Earth link. Since the link advantage of going to a higher frequency increases as the ratio of the frequencies squared, a shift to Ka band (32 GHz) provides a theoretical increase of 11.6 dB over X band (8.4 GHz). However, the actual advantage is somewhat smaller due to increased atmospheric effects at Ka band and because of antenna imperfections that are less significant at X band. In practice, a shift to Ka band has been demonstrated to add 5 dB of gain over X band in flight experiments.[16] This added gain could be used to substantially increase the data return capability of the MarsSat network. Tighter spacecraft antenna pointing control would be necessary because of the narrower, more focused beam.

The printed reflectarray antenna consists of a very thin, flat reflecting surface and an illuminating feed. The reflector surface consists of many printed microstrip patches, or dipoles, which can be implemented without any power division network. The feed illuminates the printed elements which, in turn, are designed to reradiate the incident field with a planer phase front in a specified direction. Because of the phase adjustment capability of the patch elements, the reflecting surface can be flat or conformal to the mounting structure and still maintain a constant phase aperture field. The antenna's flat structure can be more easily and reliably deployed than a parabolic reflector to form a large aperture with relatively low volume. Alternatively, since a large portion of the antenna (except for its feed element) is a flat structure with low profile, it can be conformally mounted onto a spacecraft's outside structure. The reflectarray antenna can be integrated with solar array cells to optimally utilize spacecraft surface area and minimize overall mass.[17]

***In-situ* Communications**

The UHF transceiver payload is expected to benefit from technologies that have been previously developed at JPL as well as several that are currently in-progress.

The navigation capabilities of the transceiver will be based on the highly digital, radio metric tracking techniques employed in JPL's BlackJack family of space GPS receivers.[18] These receivers have been designed for a variety of scientific purposes, both in support of other science experiments such as precise orbit determination of altimeter and radar platforms as well as for direct science measurements such as radio occultation of the atmosphere and ultra-precise range measurements for gravity science. The phase and range tracking techniques and algorithms, both hardware and software based, will be used in the UHF transceiver, producing high precision observables that will be used for user position as well as Mars network constellation orbit determination and time synchronization. These technologies will be available starting in the 2003 mission.

Two separate developments, also at JPL, will contribute to the miniaturization of the UHF transceiver payload. The Autonomous Formation Flyer (AFF) will pioneer several technologies that will be inherited by the Mars network transceiver. Also based on JPL's BlackJack GPS receivers, the AFF will miniaturize the microprocessor subsystem of the BlackJack, reducing mass and volume. In addition, it will employ highly flexible, programmable digital logic in its digital channelization subsystem that will also be used in the transceiver, further reducing mass as well as offering significant flexibility through reprogrammability. Both of these technologies will benefit the Mars network transceiver.

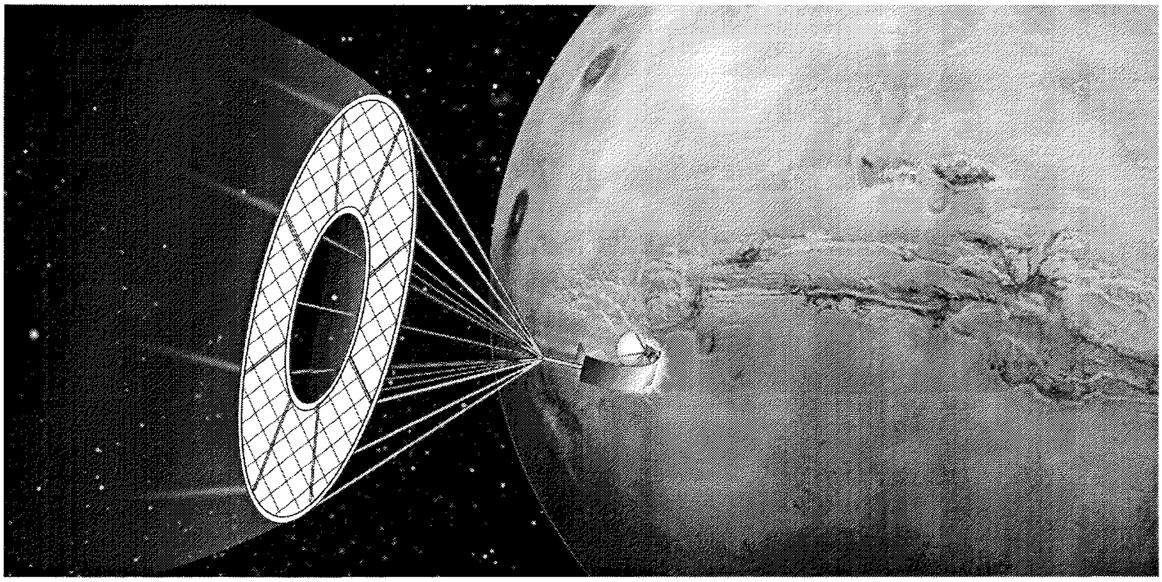

Figure 6: Ballute Aerocapture Directly into Low Mars Orbit

Directly addressing the issues of lower power, volume and mass, the Micro-Communications Avionics System (MCAS) series of transceivers is also being developed at JPL for *in-situ* communications applications. Initially designed for micro- and nano-probe applications which require extremely low mass and power consumption, the signal tracking techniques and hardware designs will be used in the UHF payload to speed development as well as to further reduce mass and power. MCAS is envisioned as a series of successively smaller and lower power transceivers. The first version, MCAS-1, will inject its technologies into the 2003 mission, whereas future generations of MCAS will benefit missions in 2005 and beyond.

Ballute for Aerocapture

A lightweight, inflatable, hypersonic drag device, called a ballute (balloon + parachute) is being studied for use in planetary atmospheres to achieve aerocapture and landing.[19, 20] Figure 6 conceptually illustrates application of the ballute for MicroSat aerocapture directly into Mars low altitude orbit and eliminating the need for lengthy aerobraking operations. The ballute was initially considered for the MicroSat in order to save ΔV and mass. Recent JPL studies indicate that the ballute could increase the dry mass delivered to final Mars orbit by 15 to 20 kg. This is a huge increase considering that the current payload allocation is only 6 kg and that the overall mass margin is very tight.

In addition to very significant mass savings, the ongoing network study indicates there are numerous very important additional benefits associated with the ballute, which derive from the fact that aerobraking would be avoided. Direct injection into low altitude Mars orbit permits timely full support of users, including those arriving on the same opportunity, for which the highest priority activities are usually those that occur in the first 1 to 3 months after arrival (e.g., aircraft, rover, sample return missions). In effect, the ballute buys one additional Mars opportunity worth of mission life, since the arrival opportunity is severely compromised for prime relay support when the design is based on aerobraking.

Use of the ballute has several other benefits: Long eclipses are avoided, which may occur during aerobraking unless constraints are imposed on initial orbit orientation and phasing of the aerobraking operations. The ballute precludes the need for achieving an aerodynamically stable design for aerobraking, which is not easily achieved within the Ariane piggyback configuration constraints, and would require careful arrangement of hardware components in addition to the probable need for drag flaps. The heavy DSN support required during aerobraking is avoided as are the high costs of the associated labor-intensive spacecraft planning, monitoring, and navigation support.

Summary

The Mars Comm/Nav MicroSat Network begins with launch of a prototype spacecraft in the 2003 time frame, and continues with deployment of two additional spacecraft to Mars at each succeeding Earth-to-Mars opportunity. Although Comm/Nav MicroSat spacecraft will utilize the standard micromission bus being developed for launch on Ariane 5 rockets, they will also have some mission-unique characteristics. Driving requirements for these spacecraft include significantly increased ΔV capability, aerobraking, higher Mars-Earth communications rates, UHF payload accommodation and longer mission lifetime. The heart of the Comm/Nav MicroSat spacecraft is the UHF transceiver for in-situ communications, currently in development. Three significant characteristics of this transceiver include: 1) an ability to support multiple, simultaneous users; 2) integration of radiometric tracking and communications functions, and; 3) a powerful microprocessor to execute high-level software for provision of user services. The payload will also include an Ultra Stable Oscillator to support the needed services. Technological advances in deep space communications will also be needed to enable the MicroSat Network. To this end, the new Spacecraft Transponding Modem, Ka-band—with high-efficiency power amplifier, and inflatable reflectarray/solar array are expected to make their first appearances on the 2003, 2005 and 2007 missions respectively. Finally, the challenging ΔV requirements of these missions will spur the use of a number of new technologies, including lightweight propulsion components in 2003, and in 2005, miniature attitude control thrusters, higher efficiency main thrusters, and ultimately, the use of ballutes for aerocapture.

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